Weathering the storm: Developments in the acoustic sensing of wind and rain

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***Abstract* — An Acoustic Rain Gauge (ARG) analyses the underwater sound levels across a wide frequency range, classifies the observed spectrum according to likely source and then determines the local wind speed or rain rate as appropriate. This paper covers a trial on the Scotian Shelf off Canada, comparing the geophysical information derived from the acoustic signals with those obtained from other sources.**

Keywords – underwater acoustics; ambient noise; wind speed; rain detection

I. Introduction

Variations in rainfall at sea are a key indicator of climate change, with increasing effort being spent on the development of new satellite instruments and techniques for measuring rain [1]. However, there is still a need for *in situ* measurements to provide validation, and for providing high temporal resolution sampling of specific locations of interest. Acoustic Rain Gauges (ARGs), developed by Jeffrey Nystuen [2-4] provide one means of doing this. Such a device samples the underwater sound field between 500 Hz and 50 kHz, classifies the observed spectrum as ‘wind only’, ‘rain-related’ or ‘contaminated by other sources’, and then uses simple algorithms to infer the wind speed [5] or rain rate [4] as appropriate.

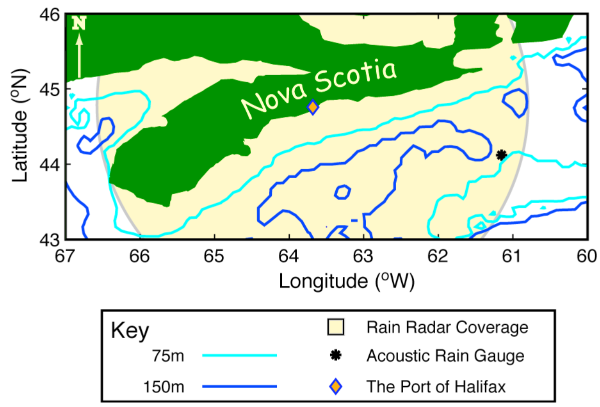

Figure 1. Deployment site of Scotian Shelf trial. The blue lines are isobaths and the shaded circle indicates the limit of the radar coverage.

Southampton Oceanography Centre has been involved in the testing of ARGs for many years, with a concentration of emphasis on mid-latitude rain systems. Initial trials were in Scottish lochs and then off the coast of Wales [6]; this paper covers the deployment of an ARG on the Scotian Shelf off Canada (Fig. 1). The ARG was deployed in 70m of water, with the hydrophone suspended 30m below the surface. A Canadian met buoy, with wind vane and optical rain gauge (ORG), was deployed ~8 km away, and the whole region was just within the coverage of the rain radar system on Nova Scotia.

II. Details of Scotian Shelf Trial

The SOC Mark IV rain gauge (Fig. 2) is 3.4m long, with most of the buoy being occupied by batteries, and the electronic circuitry in the top compartment for measuring the acoustic signal, logging it, and relaying a subset via satellite. The hydrophone hangs freely on an umbilical cable from the bottom of the buoy, whilst a series of small floats prevents the mooring line from entangling it. The rain radar based on Nova Scotia scans the area every 10 minutes; consequently the raw data from the ARG and from the met buoy were averaged over 10-min intervals.

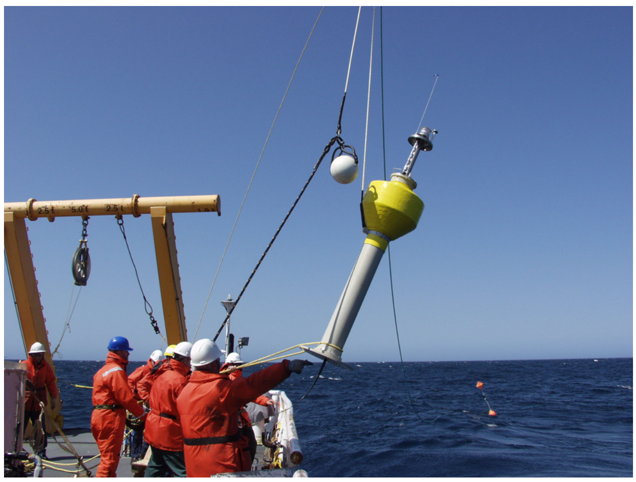

Figure 2. Deployment of Mk IV ARG from CFAV Quest. [Photo courtesy of Dan Hutt.]

III. Results

In the absence of rain or nearby shipping, the underwater acoustic spectrum between 1 and 10 kHz is linear (see Fig. 3), with the intensity at all frequencies increasing with wind speed. A wind speed algorithm has been developed by previous researchers [5] using the intensity at 8 kHz, as that is immune to the sounds of distant shipping and light rain.

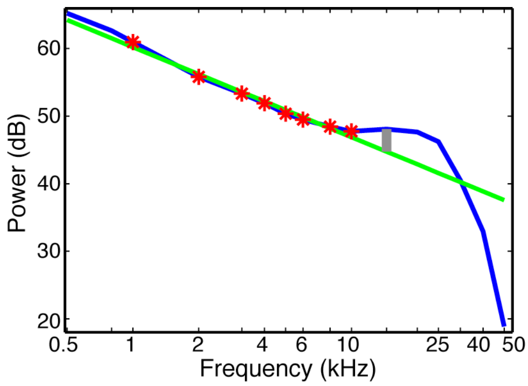

Figure 3. Illustration of underwater spectra associated with rain. The blue line shows all 16 frequencies recorded; the green line is a linear fit to the 8 values in the range 1-10 kHz (highlighted by the red asterisks). The grey bar indicates the enhancement at 14.5 kHz due to the 'drizzle peak'.

The acoustic intensities we observe at 8 kHz show a close correlation with the wind values from the met buoy (see Fig. 4), with very little spread in the acoustic values (in logarithmic units) at high wind speeds. However, the mean relationship we observe is about 7dB higher than that expected; consequently a simple application of the algorithm of Vagle et al. [5] leads to wind speeds a factor of two too large. Possible causes of this discrepancy are erroneous calibration of our systems and/or increased ambient sound levels due to bottom reflections or acoustic refraction near the surface.

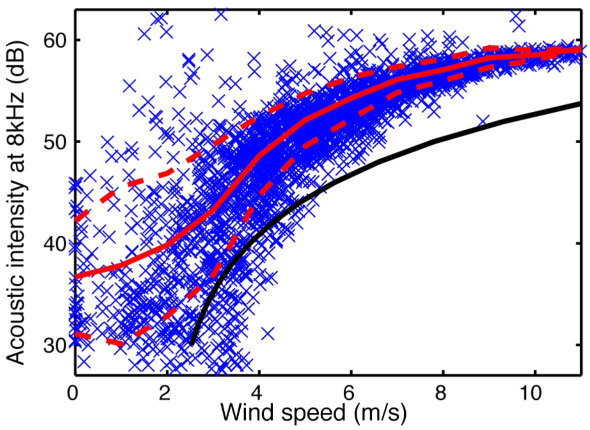

Figure 4. Scatter plot of acoustic intensity at 8 kHz as a function of wind speed. Blue crosses indicate individual 10-min averages, with the solid red line showing the mean relationship, and the dashed lines indicating the spread (±1 std. dev.). The solid black curve gives the relationship noted previously for the deep N. Atlantic [5].

There was little rain during the period of the deployment; Fig. 5 shows one of the few periods of considerable rain. The absolute values determined by the Optical Rain Gauge are not fully trustworthy (with values in excess of 300mm hr^{-1} being occasionally reported), but are usually indicative of rain events. The spatial patterns of rain are shown by images from the rain radar; from these we made a rough estimate of the rain intensity (Fig. 5b). Corresponding features are found in the acoustic data.

For this deployment, the spectral slope (Fig. 5c) was typically –15 dB/decade. The presence of heavy rain, with a large range of drop sizes creating impact and bubble noise is predicted to reduce the magnitude of the spectral slope [3]. This effect is most clear at the start of Day 158 (June 7th 2002); however, there are also intermittent signals during the rain periods of Day 157.65-157.85 and Day 158.4-158.6. The spectral change at Day 158.85 has no counterpart in either of the validation datasets.

The small drops in light rain or drizzle are particularly efficient at creating bubbles that resonate around 13-20 kHz [2], leading to a 'drizzle peak' in the spectrum as shown in Fig. 3. When no rain is present, the 'enhancement' at 14.5 kHz is usually negative, as the observed spectrum tends to fall away from the fitted line due to attenuation by a bubble foam and the lower sensitivity of the hydrophone for higher frequencies. However, the rain events of Day 158.0-158.1 and Day 158.5-158.6 show a clear signal of the 'drizzle peak'. It may be inferred that small raindrops were scarce during the event of Day 1576.6-157.8.

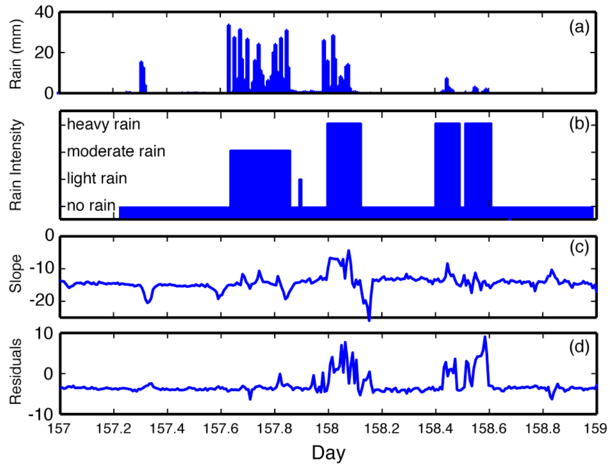

Figure 5. Variation of rain records during two days. a) Rain rate from ORG. b) Rain rate deduced from rain radar. c) Spectral slope over 1-10 kHz. d) Size of drizzle peak at 14 kHz (residuals above fitted line — see Fig. 3).

IV. Summary

The deployment of an ARG off Canada was a partial success. The acoustic intensity at 8 kHz showed a reasonable correspondence with local wind speed, but the actual values were 7 dB higher than expected from the work of others. This is still being investigated. The actual period of the deployment contained very little rain. A number of events can be found for which the acoustic data agree with the detection of rain by the optical rain gauge and the rain radar. However, these two sources of validation data do not always agree on the magnitude of rain events.

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